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THE PHYSICS OF SPIN-POLARIZED ATOMIC VAPORS. (U)
MAY 81 W HAPPER

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Final Report

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THE PHYSICS OF SPIN-POLARIZED ATOMIC VAPORS

W. Happer

Columbia Radiation Laboratory, Department of Physics

Columbia University, New York, New York 10027

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A. D. BLOSE
Technical Information Officer

I. RESEARCH OBJECTIVES

The overall objective of the work supported by the Air Force Office of Scientific Research grant AFOSR-79-0082 has been to explore the basic physical properties of spin polarized atomic vapors. These systems are of considerable interest to the civilian and military sectors of our society because they can be used to make very precise measurements of time, absolute rotation rates, and electromagnetic fields. For example, the U.S. time standard is the atomic cesium hyperfine frequency; very precise atomic frequency standards are used in satellites and on earth for a wide variety of uses. Optically pumped magnetometers are used by the oil and mining industry for prospecting, by archaeologists for locating lost cities and sunken treasure ships, and by the navy for location of submarines. Optically pumped systems are currently being developed for use as gyroscopes which may have real advantages in terms of ruggedness and economy.

In spite of the widespread practical utility of these systems, there is only limited research going on in related areas. There are no more than a dozen active research groups world wide and most are in foreign countries, including several excellent laboratories in the Soviet bloc.

The goal of our work under grant AFOSR-79-0082 has been to maintain a center of excellence for the study of spin polarized atomic vapors, to ensure that outstanding students are introduced to the field from time to time and to coordinate our research activities with the needs of industrial and government laboratories for critical information and the needs of the university for high-quality basic research.

II. ACCOMPLISHMENTS

Some of the most important accomplishments which have resulted from work supported by grant AFOSR-79-0082 are listed below. While the main thrust of our effort has been the study of spin-polarized atomic vapors, accidental discoveries during the course of this work have led to several new lines of research, some of which are now receiving independent support from other agencies.

A. Spin Destruction in Collisions Between Alkali Atoms

The evolution of spin polarization due to collisions between ground-state atoms in $^2S_{1/2}$ states is dominated by spin exchange. Recently we have shown that collisions between alkali atoms also destroy the electronic spin at a rate which is about 1% of the spin exchange rate. This spin destruction is probably due to magnetic dipole spin-spin interactions, and it has important consequences for various optically pumped devices. The work is described in Phys. Rev. Letters 44, 930 (1980).

B. Light Narrowing of Magnetic Resonance Lines in Dense Alkali Vapors

While investigating spin exchange collisions in dense, laser-pumped alkali vapors we noticed that a pronounced narrowing of the magnetic resonance linewidth occurred when the laser beam intensity increased. In all other experiments known to us, an increase in the optical intensity causes the magnetic resonance linewidth to broaden. More careful experimental and theoretical studies of this light narrowing phenomenon showed that it was due to the interplay of the optical pumping with the peculiar properties of spin exchange collisions. The phenomenon may be

of importance in some optically pumped devices. The results of our work will appear in the April 1981 issue of the Physical Review A.

C. The Role of NaXe Molecules in the Spin Relaxation of Optically Pumped Na in Xe Gas

Recent work on nmr gyroscopes at Litton Industries has made use of Xe^{129} and Xe^{131} nuclei which were polarized by spin exchange with optically pumped rubidium atoms. Since the efficiency of spin polarization depends on the relative magnitudes of spin exchange and spin destruction during a collision we thought that sodium might be a more favorable element than rubidium, since sodium has a smaller nuclear charge Z and might therefore have smaller spin orbit interactions and spin destruction rates in collisions with xenon atoms. We were surprised and disappointed to find that the spin destruction rates of sodium in xenon were even greater than the rate for rubidium in xenon. The reason may be that most of the depolarization occurs while the valence electron is within the xenon atom rather than in the field of the alkali ion. At any rate, there is now no reason to believe that sodium would be any better than rubidium as a collision partner for polarizing xenon nuclei.

III. JOURNAL ARTICLES PUBLISHED
BETWEEN MARCH 1, 1979 AND MARCH 1, 1981

N. D. Bhaskar, E. Zouboulis, T. McClelland, and W. Happer, "New Infrared Absorption Bands of Alkali Vapors," Phys. Rev. Lett. 42, 640 (1979).

N. D. Bhaskar, M. Hou, B. Suleman, and W. Happer, "Propagating Optical Pumping Wavefronts," Phys. Rev. Lett. 43, 519 (1979).

E. Zouboulis, N. D. Bhaskar, A. Vasilakis, and W. Happer, "New Infrared Absorption Bands of Cesium Vapor," Journal of Chem. Phys. 72, 2356 (1980).

R. Novak, N. D. Bhaskar, and W. Happer, "Infrared Emission Bands from Transitions between Excited States of Cesium-Noble Gas Molecules," J. Chem. Phys. 71, 4052 (1979).

J. Liran, J. Pietras, J. Camparo, and W. Happer, "Optical Pumping of Cesium Atoms with Second Resonance Light," Opt. Commun. 31, 169 (1979).

N. D. Bhaskar, J. Pietras, J. Camparo, J. Liran, and W. Happer, "Spin Destruction in Collisions between Cesium Atoms," Phys. Rev. Lett. 44, 930 (1980).

N. D. Bhaskar, M. Hou, M. Ligare, B. Suleman, and W. Happer, "Role of Na-Xe Molecules in Spin Relaxation of Optically Pumped Na in Xe Gas," Phys. Rev. A 22, 2710 (1980).

IV. COLLOQUIA, SEMINARS, AND PAPERS PRESENTED
AT SCIENTIFIC MEETINGS BY PERSONNEL OF GRANT AFOSR-79-0082

- W. Happer, "Alkali Xenide Molecules," Colloquium, Department of Physics, Stevens Institute of Technology, Hoboken, New Jersey, December 12, 1979.
- W. Happer, "Laser Studies of Spin Polarized Atomic Vapors," Colloquium, Department of Physics, Columbia University, New York, New York, January 25, 1980.
- R. Novak, N. Bhaskar, and W. Happer, "Infrared Excimer Emission Bands from Transitions between Excited States of Cesium-Noble Gas Molecules," Optical Society of America Topical Meeting on Excimer Lasers, Charleston, South Carolina, September 11-13, 1979.
- W. Happer, "Dense Alkali Vapors," Seminar, Massachusetts Institute of Technology, Cambridge, Massachusetts, April 16, 1980; Colloquium, State University of New York, Binghamton, New York, April 25, 1980; Colloquium, College of William and Mary, Williamsburg, Virginia, January 23, 1981.
- W. Happer, "Optical Pumping for Combustion Diagnostics," Sandia Laboratories, Livermore, California, February 12, 1981.
- N. Bhaskar, "Alkali Vapors-Optical Pumping Photochemistry," Department of Applied Physics and Engineering, Princeton University, Princeton, New Jersey, September 19, 1980; Exxon Research Center, Linden, New Jersey, January 6, 1981.

V. PERSONNEL

Many excellent young scientists have received their training with support from Grant AFOSR-79-0082 at Columbia. They are now continuing to contribute to the technological base of the United States in government, industry and the universities. Senior research staff and graduate students are listed below.

Senior Research Staff

| | |
|----------------|---|
| Dr. W. Happer | (principal investigator at Columbia University until August 31, 1980; at Princeton University from September 1, 1980 to present). |
| Dr. N. Bhaskar | (at Columbia University until August 31, 1980; at Princeton University from September 1, 1980 to present). |
| Dr. Zeng Xizhi | (visitor from Wuhan Institute of Physics, China). |
| Dr. Lu Yi-Qun, | (visitor from Anhui Institute of Optics and Fine Mechanics China). |
| Dr. J. Liran | (visitor from Nuclear Research Centre, Negev, Beer-Sheva, Israel; at Columbia from August 1, 1978 - August 1, 1979). |

Graduate Students

| | |
|-------------------|---|
| Dr. J. Pietras | (Ph.D. 1980; now at EMI Division of Schlumberger, Princeton, New Jersey). |
| Dr. J. Camparo | (Ph.D. 1981; now at the Aerospace Corporation, Los Angeles, California). |
| Dr. M. Y. Hou | (Ph.D. 1980; now at Peking University, China). |
| Mr. T. McClelland | |
| Mr. B. Suleman | |
| Mr. A. Sharma | |

VI. INTERACTIONS OF RESEARCH STAFF
WITH THE SCIENTIFIC AND TECHNOLOGICAL COMMUNITY

Personnel involved in Grant AFOSR-79-0082 have had many fruitful interactions with other programs of interest to the Air Force. Dr. Happer serves as a consultant to several research groups in industry which are working on optically pumped gyroscopes with Air Force or internal support. He has contributed to the work on the mercury gyroscope at Kearfott Singer, to the work on the xenon-krypton gyroscope at Litton Industries, and to the work on mercury gyroscopes at Bendix. He has also advised the Air Force and other parts of the Department of Defense through his work in the consulting group JASON. He has also been quite closely involved with nonacoustic submarine detection for the Navy. All of this work has benefited from the research supported by Grant AFOSR-79-0082 at Columbia and at Princeton University.

Dr. Bhaskar has worked closely with Litton Industries on problems associated with spin polarized Xe^{129} and Xe^{131} . He has been invited to spend the summer of 1981 working at Litton Industries with the atomic physics group.

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A review of some of the main achievements of work on spin polarized alkali vapors and their relevance to magnetometers, gyroscopes and other devices is presented. Personnel histories, scientific publications and interactions within the technical community are also summarized. | | | |

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